Concepts of Object-Oriented Programming

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5. Information Hiding and Encapsulation

Information Hiding

- Definition
  Information hiding is a technique for reducing the dependencies between modules:
  - *The intended client is provided with all the information needed to use the module* ***correctly****, and* ***with nothing more***
  - *The client uses only the (publicly) available information*

- Information hiding deals with programs, that is, with static aspects
- Contracts are part of the exported interfaces

Objectives

- Establish strict interfaces
- Hide implementation details
- Reduce dependencies between modules
  - Classes can be studied and understood in isolation
  - Classes interact only in simple, well-defined ways

```
class Set {
  …
  // contract or documentation
  public void insert( Object o )
      { … }
}
```

```
class BoundedSet {
  Set rep;
  int maxSize;

  public void insert( Object o ) {
    if ( rep.size( ) < maxSize )
      rep.insert( o );
  }
}
```

The Client Interface of a Class

- Class name
- Type parameters and their bounds
- Super-interfaces
- Signatures of exported methods and fields
- Client interface of direct superclass

```
class SymbolTable
        extends Dictionary<String,String>
        implements Map<String,String> {
  public int size;

  public void add( String key, String value )
   { put( key, value ); }

  public String lookup( String key )
        throws IllegalArgumentException {
   return atKey( key );
  }
}
```

What about Inheritance?

- Is the name of the superclass part of the client interface or an implementation detail?

- In Java, inheritance is done by subclassing
- Subtype information must be part of the client interface

```
class SymbolTable {
  Dictionary<String,String> rep;

  public SymbolTable( )
   { … }
  public void
     add( String key, String value )
   { … }
  public String lookup( String key )
   { … }
}
```

```
Dictionary<String,String> d;
d = new SymbolTable();
d.put( "var", "5" );
```

The Client Interface of a Class

- Class name
- Type parameters and their bounds
- Super-class
- Super-interfaces
- Signatures of exported methods and fields
- Client interface of direct superclass

```
class SymbolTable
        extends Dictionary<String,String>
        implements Map<String,String> {
  public int size;

  public void add( String key, String value )
   { put( key, value ); }

  public String lookup( String key )
        throws IllegalArgumentException {
   return atKey( key );
  }
}
```

Other Interfaces

- Subclass interface
  - Efficient access to superclass fields
  - Access to auxiliary superclass methods
- Friend interface
  - Mutual access to implementations of cooperating classes
  - Hiding auxiliary classes
- And others

```
package coop.util;
public class DList {
  protected Node first, last;
  private int modCount;
  protected void modified( )
    { modCount++; }
  …
}
```

```
package coop.util;
/* default */ class Node {
  /* default */ Object elem;
  /* default */ Node next, prev;
  … }
```

Expressing Information Hiding

- Java: Access modifiers
  - **public** client interface
  - **protected** subclass + friend interface
  - Default access friend interface
  - **private** implementation

- Eiffel: Clients clause in feature declarations
  - **feature** { ANY } client interface
  - **feature** { T } friend interface for class T
  - **feature** { NONE } implementation (only "**this**"-object)
  - All exports include subclasses

Safe Changes

- Consistent renaming of hidden elements
- Modification of hidden implementation as long as exported functionality is preserved
- Access modifiers and clients clauses specify what classes might be affected by a change

```
package coop.util;

public class DList {

  protected Node first, last;

  private int version;
  protected void modified( )
    { version++; }
  …
}
```

Exchanging Implementations

- Observable behavior must be preserved
- Exported fields limit modifications severely
  - Use getter and setter methods instead
  - Uniform access in Eiffel
- Modifications are critical
  - Fragile baseclass problem
  - Object structures

```
class Coordinate {
  private double x,y;
  …
  public double distOrigin( )
   { return Math.sqrt( x*x + y*y ); }
}
```

```
class Coordinate {
  private double radius, angle;
  …
  public double distOrigin( )
   { return radius; }
}
```

Method Selection in Java (JLS1)

- At compile time:
  1. Determine static declaration
  2. Check accessibility
  3. Determine invocation mode (virtual / nonvirtual)
- At run time:
  4. Compute receiver reference
  5. Locate method to invoke (based on dynamic type of receiver object)

```
class T {
  public void m( ) { ... }
}
```

```
class S extends T {
  public void m( ) { ... }
}
```

```
class U extends S { }
```

```
T v = new U( );
v.m( );
```

Rules for Overriding: Access

- Access Rule:
  The access modifier of an overriding method must provide at least as much access as the overridden method

Default access → protected → public

```
class Super {
  …
  protected void m( ) { … }
}
```

```
class Sub extends Super {
  public      void m( ) { … }
}
```

In class Super or Sub:

```
public void test( Super v ) {
  v.m( );
}
```

Rules for Overriding: Hiding

- Override Rule:
  A method Sub.m overrides the superclass method Super.m only if Super.m is accessible from Sub
- If Super.m is not accessible from Sub, it is hidden by Sub.m
- Private methods cannot be overridden

```
class Super {
  …
  private void m( )
    { System.out.println("Super"); }
  public void test( Super v )
    { v.m( ); }
}
```

```
class Sub extends Super {
  public void m( )
    { System.out.println("Sub"); }
}
```

```
Super v = new Sub( );
v.test( v );
```

Problems with Default Access Methods

- S.m does not override T.m (T.m is not accessible in S)
- T.m and S.m are different methods with same signature
- Static declaration for invocation is T.m
- At run time, S.m is selected and invoked

```
package PT;
public class T {
  void m( ) { ... }
}
```

```
package PS;
public class S extends PT.T {
  public void m( ) { ... }
}
```

In package PT:

```
T v = new PS.S( );
v.m( );
```

Corrected Method Selection (JLS2)

- Dynamically selected method must override statically determined method

- At compile time:
  1. Determine static declaration
  2. Check accessibility
  3. Determine invocation mode (virtual / nonvirtual)

- At run time:
  4. Compute receiver reference
  5. Locate method to invoke that overrides statically determined method

Problems with Protected Methods

- S.m overrides T.m
- Static declaration is T.m, which is accessible for C
- At run time, S.m is selected, which is not accessible for C
- **protected** does not always "provide at least as much access" as **protected**

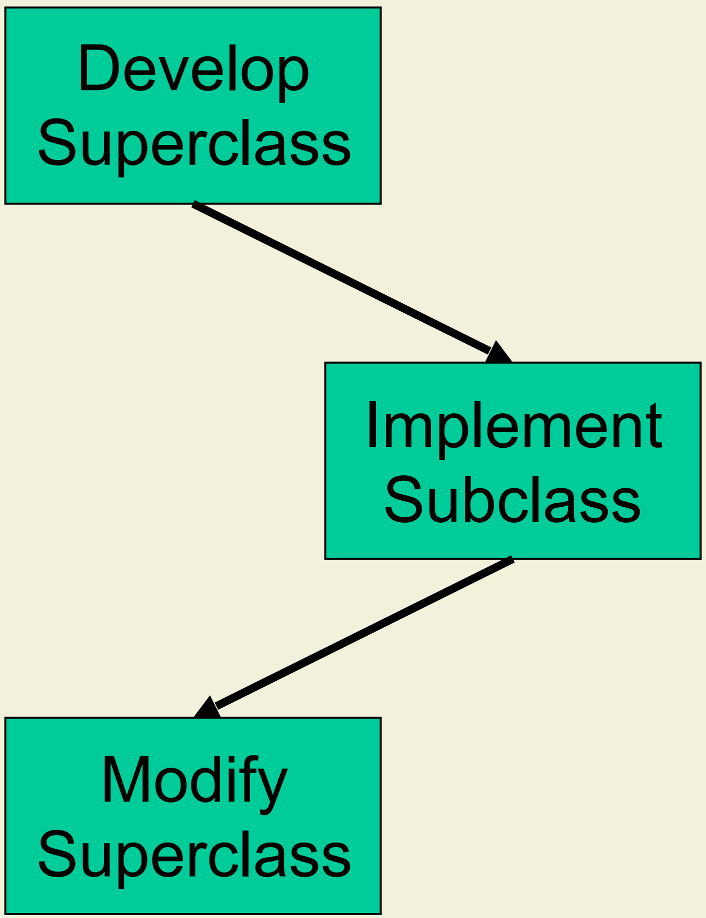
```
package PT;
public class T {
  protected void m( ) { ... }
}
```

```
package PS;
public class S extends PT.T {
  protected void m( ) { ... }
}
```

public would be safe

```
package PT;
public class C {
  public void foo( ) {
    T v = new PS.S( );
    v.m( );                }
}
```

Another Fragile Baseclass Problem

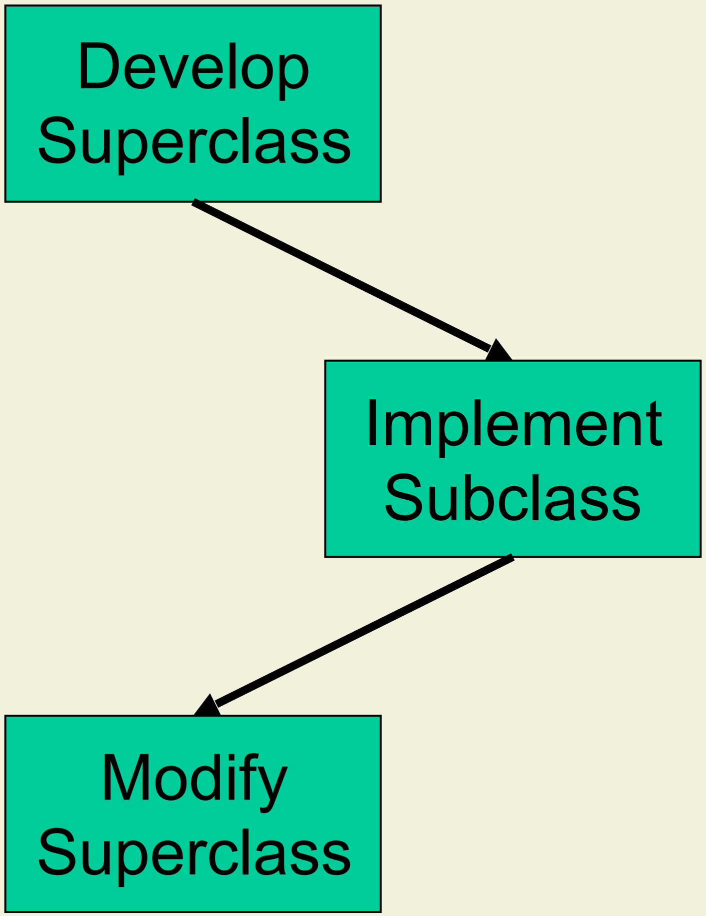



```
class C {
  int x;
  public    void inc1( )
    { this.inc2( ); }
  private   void inc2( )
    { x++; }
}
```

```
class CS extends C {
  public    void inc2( )    { inc1( ); }
}
```

```
CS cs = new CS( 5 );
cs.inc2( );
System.out.println( cs.x );
```

Another Fragile Baseclass Problem




```
class C {
  int x;
  public    void inc1( )
    { this.inc2( ); }
  protected void inc2( )
    { x++; }
}
```

```
class CS extends C {
  public    void inc2( )    { inc1( ); }
}
```

```
CS cs = new CS( 5 );
cs.inc2( );
System.out.println( cs.x );
```

5. Information Hiding and Encapsulation

5.1 Information Hiding

5.2 Encapsulation

Objective

- A well-behaved module operates according to its specification in any context, in which it can be reused
- Implementations rely on consistency of internal representations
- Reuse contexts should be prevented from violating consistency

```
class Coordinate {
  public double radius, angle;
  // invariant 0 <= radius &&
  //  0 <= angle && angle < 360
  …
  // ensures  0 <= result
  public double distOrigin( )
    { return radius; }
}
```

```
Coordinate c = new Coordinate( );
c.radius = -10;
Math.sqrt( c.distOrigin( ) );
```

Encapsulation

- Definition
  Encapsulation is a technique for structuring the state space of executed programs. Its objective is to guarantee data and structural consistency by establishing capsules with clearly defined interfaces.

- Encapsulation deals mainly with dynamic aspects
- Information hiding and encapsulation are often used synonymously in the literature;
  here, encapsulation is a more specific concept

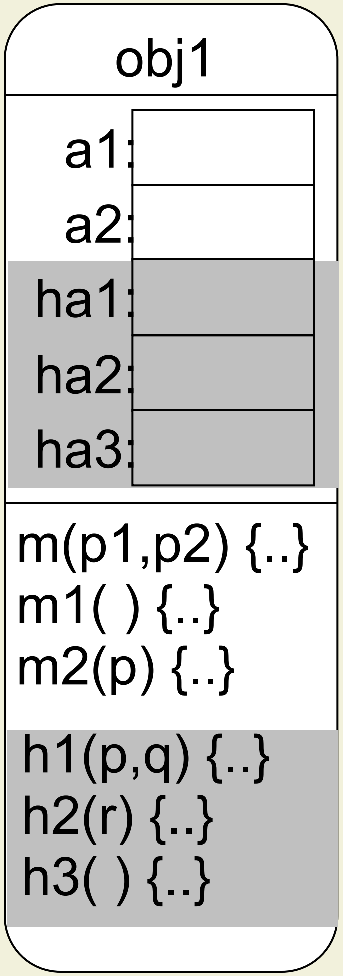
Levels of Encapsulation

- Capsules can be
  - Individual objects
  - Object structures
  - A class (with all of its objects)
  - All classes of a subtype hierarchy
  - A package (with all of its classes and their objects)

- Encapsulation requires a definition of the boundary of a capsule and the interfaces at the boundary

Consistency of Objects

- Objects have (external) interfaces and an (internal) representation
- Consistency can include
  - Properties of one execution state
  - Relations between execution states
- The internal representation of an object is encapsulated if it can be manipulated only by using the object's interfaces



Example: Breaking Consistency (1)

Use **private**

- Problem:
  Exported fields allow objects to manipulate the state of other objects

- Solution:
  Apply proper information hiding

```
class Coordinate {
  public double radius, angle;
  // invariant 0 <= radius &&
  //  0 <= angle && angle < 360
  …
  // ensures  0 <= result
  public double distOrigin( )
    { return radius; }
}
```

```
Coordinate c = new Coordinate( );
c.radius = -10;
Math.sqrt( c.distOrigin( ) );
```

Example: Breaking Consistency (2)

- Problem:
  Subclasses can introduce (new or overriding) methods that break consistency
- Solution:
  Behavioral subtyping

```
class Coordinate {
  protected double radius, angle;
  // invariant 0 <= radius &&
  //       0 <= angle && angle < 360
  …
  public double getAngle( )
    { return angle; }
}
```

```
class BadCoordinate
           extends Coordinate {
  public void violate( )
    { angle = -1; }
}
```

```
BadCoordinate c =
    new BadCoordinate( );
c.violate( );
Math.sqrt( c.getAngle( ) );
```

Achieving Consistency of Objects

1. Apply information hiding:
   Hide internal representation wherever possible
2. Make consistency criteria explicit:
   Use contracts or informal documentation to express consistency criteria (e.g., invariants)
3. Check interfaces:
   Make sure that all exported operations of an object – including subclass methods – preserve all documented consistency criteria

Invariants

- Invariants express consistency properties
- The invariant of object o has to hold in:
  - Prestates of o's methods
  - Poststates of o's methods
- Temporary violations possible

```
class Redundant {
  private int a, b;
  // invariant a == b
  …
  public void set( int v ) {
    // prestate: invariant holds
    a = v;
    // invariant does not hold
    b = v;
    // poststate: invariant holds
  }
}
```

Checks for Invariants: Textbook Solution

- Assume that all objects o are capsules
  - Only methods executed on o can modify o's state
  - The invariant of object o only refers to the encapsulated fields of o

- For each invariant, we have to show
  - That all exported methods preserve the invariants of the receiver object
  - That all constructors establish the invariants of the new object

Object Consistency in Java

- Declaring all fields **private** does not guarantee encapsulation on the level of individual objects
- Objects of same class can break the invariant
- Eiffel supports encapsulation on the object level
  - **feature** { NONE }

```
class Redundant {
  private int a, b;
  private Redundant next;
  // invariant a == b
  …
  public void set( int v ) { … }

  public void violate( ) {
    // all invariants hold
    next.a = next.b + 1;
    // invariant of next does not hold
  }
}
```

Invariants for Java (Simple Solution)

- Assumption: The invariants of object o may only refer to private fields of o
- For each invariant, we have to show
  - That all exported methods and constructors of class T preserve the invariants of all objects of T
  - That all constructors in addition establish the invariants of the new object

References

- James Gosling, Bill Joy, Guy Steele, Gilad Bracha, and Alex Buckley: *The Java Language Specification. 2013* http://docs.oracle.com/javase/specs/

- Peter Müller and Arnd Poetzsch-Heffter: *Kapselung und Methodenbindung: Javas Designprobleme und ihre Korrektur.* Java-Informations-Tage, 1998 (in German)